An Adaptive Per-Survivor Processing Algorithm

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***Abstract*—We propose an adaptive and parameter-independent per-survivor processing algorithm to improve the receiver performance on time-varying channels. With a variable step size for a plurality of survivor paths, this new method eliminates the dependency of all the survivor paths and improves the convergence rate of channel estimation.**

***Index Terms*—Doppler shift, joint data detection and channel estimation, per-survivor processing, time-varying channels, wireless communications.**

I. Introduction

DIGITAL communication over time-varying wireless channels results in both data detection and channel estimation problems at the receiver side. The well-known maximum-likelihood sequence estimation (MLSE) [1] represents the optimum data decoding scheme under the assumption that the receiver perfectly knows the channel parameters. In time-varying environments, several new adaptive MLSE algorithms for unknown channels were proposed in [2], [5], and [6], including joint channel and data estimation based on per-survivor processing (PSP). PSP embeds the data-aided channel estimation into the Viterbi algorithm. Each state in the PSP has a separate channel impulse response (CIR) estimate which is based on the survivor path leading to that state. The CIR update in the PSP for each state is carried without any decision delay. This algorithm exhibits considerable improvement, compared to the conventional adaptive MLSE.

In the PSP decoder, the least mean square (LMS), recursive least squares (RLS) and Kalman filter [4] algorithms can be used to estimate the channel parameters. In this paper, only LMS is investigated due to its implementation simplicity. The accuracy and the convergence properties of LMS determine the overall performance of the PSP algorithm. In the time-varying channel, the convergence rate of LMS is governed by the step-size parameter β, which determines the tracking ability and convergence rate of the LMS. The conventional PSP was based on fixed step-size LMS. But in a time-varying multipath and Doppler-shift environment, there is no fixed optimized step-size parameter that can estimate the channel well all the time, because the receiver has no knowledge of the terminal speed and other fast changing channel parameters. Without the ability of optimizing the step-size factor, the performance of the PSP will have a significant degradation in dynamic channel conditions. Because of this drawback, the conventional PSP algorithm with fixed step size is impractical. Its performance with optimal step size becomes the high bound for the practical PSP algorithm without optimized step size. The degradation due to this unoptimized step size is significant and will be shown in Section III. To tackle this problem, an adaptive PSP is proposed in this paper that can speed up the convergence rate and improve the performance of the PSP in time-varying wireless channels without optimizing the step size. This variable step-size approach is applied to each survivor path individually eliminating any dependence between all survivor paths in the original PSP approach.

In [3], variable step-size LMS (VS-LMS) algorithms were analyzed and tested in the steady environment which showed its promise of overcoming the slow convergence rate. However, the performance of the VS-LMS algorithms on time-varying channels has not been studied. The proposed adaptive PSP will show that VS-LMS algorithms can also improve the system performance in dynamic environments, due to the high accuracy of the data-aided channel estimation in PSP. The VS-LMS algorithms suffer from another drawback, i.e., the performance is very sensitive to the selection of a parameter α, representing the step-size updating factor. An optimal α has to be determined before applying VS-LMS. Basically, the algorithm transfers the performance dependency on step size β into the dependency on step-size updating factor α. In this letter, we proposed a new step-size updating scheme which is independent of any parameters. This new channel estimator can approach the optimum performance of the PSP with optimal step size in highly dynamic channels without any knowledge of the speed and channel conditions.

II. Algorithm

The estimated channel parameters, $\underline{\hat{h}}(\mu_n)$ of each state μ_n at time n in a PSP-based [2] approach is

$$\underline{\hat{h}}(\mu_n) = F_{h(t)}\left[r(t), \{\hat{a}_j(\mu_n)\}_{j=-\infty}^{n-1}\right] \tag{1}$$

where $F_{h(t)}[o]$ denotes the function that estimates $\underline{\hat{h}}$ based on the received signal $r(t)$ and the estimated data symbols $\hat{a}_j$ on the survivor path. These survivor estimates may then be used in the computation of the branch metrics

$$\lambda(\mu_n \to \mu_{n+1}) = F_{VA}\left(\mu_n \to \mu_{n+1}, r(t), \underline{\hat{h}}(\mu_n)\right). \tag{2}$$

If the channel estimation is based on the LMS algorithm, then the channel estimation and update will be as follows. An $(L+1)$-element vector for the CIR may be defined as

$$\underline{\hat{h}}(\mu_n) = \left[\hat{h}_0(n), \hat{h}_1(n), \ldots, \hat{h}_L(n)\right]^t. \tag{3}$$

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The data vector may be defined as

$$\underline{\hat{a}}(\mu_n \to \mu_{n+1}) = [\hat{a}_n(\mu_n \to \mu_{n+1}), \hat{a}_{n-1}(\mu_n \to \mu_{n+1}), \ldots, \hat{a}_{n-L}(\mu_n \to \mu_{n+1})]^t. \quad (4)$$

The error for each path is computed as

$$e(\mu_n \to \mu_{n+1}) = r(t = nT_s) - \underline{\hat{h}}^*(\mu_n)\underline{\hat{a}}(\mu_n \to \mu_{n+1}). \quad (5)$$

The channel will be updated at each symbol period for all the survivor paths as

$$\underline{\hat{h}}(\mu_{n+1}) = \underline{\hat{h}}(\mu_n) + \beta e(\mu_n \to \mu_{n+1})\underline{\hat{a}}^*(\mu_n \to \mu_{n+1}) \quad (6)$$

where $*$ represents complex conjugate transpose of a matrix. The updated channel coefficients are then used to compute the branch metrics in the next stage, which determine the next set of survivor paths.

The proposed adaptive PSP is concerned with making the PSP algorithm of (6) adaptive for a mobile environment. In (6), the step-size factor used in the LMS algorithm for all the survivor paths is the same and fixed. Here, we choose a variable step-size factor for each path based on the estimated data sequence related to the survivor path. This will essentially break and separate all possible dependencies between different paths to estimate the CIR, and for a fast time-varying system, this can improve the performance considerably.

To take advantage of the VS-LMS algorithm in the PSP, for each state of the trellis, the associated channel coefficients will be estimated with the survivor path which ends in the state and a variable step-size parameter which is also decided by the survivor path. Therefore, the new channel estimator can be expressed as

$$\underline{\hat{h}}(\mu_{n+1}) = \underline{\hat{h}}(\mu_n) + \beta(\mu_n \to \mu_{n+1})e(\mu_n \to \mu_{n+1}) \times \underline{\hat{a}}^*(\mu_n \to \mu_{n+1}). \quad (7)$$

Notice the step-size parameter $\beta(\mu_n \to \mu_{n+1})$ becomes a vector indexed by each survivor path and is adjustable individually with time. This variable step-size can be updated using the variable step-size algorithms when the survivor paths progress.

The variable step-size LMS algorithm [3] updates the step size by multiplying (adding) or dividing (subtracting) the previous step size by a factor in the adaptation process

$$\begin{aligned}\beta(\mu_n \to \mu_{n+1}) &= \beta(\mu_{n-1} \to \mu_n) \times \alpha, \text{ if} \\ \beta(\mu_n \to \mu_{n+1}) &< \beta_{\max} \\ \beta(\mu_n \to \mu_{n+1}) &= \frac{\beta(\mu_{n-1} \to \mu_n)}{\alpha}, \text{ if} \\ \beta(\mu_n \to \mu_{n+1}) &> \beta_{\min}\end{aligned} \quad (8)$$

where α is the step-size updating factor and $\alpha > 1$; or

$$\begin{aligned}\beta(\mu_n \to \mu_{n+1}) &= \beta(\mu_{n-1} \to \mu_n) + \alpha', \text{ if} \\ \beta(\mu_n \to \mu_{n+1}) &< \beta_{\max} \\ \beta(\mu_n \to \mu_{n+1}) &= \beta(\mu_{n-1} \to \mu_n) - \alpha', \text{ if} \\ \beta(\mu_n \to \mu_{n+1}) &> \beta_{\min}\end{aligned} \quad (9)$$

where α' is the step-size updating factor and $\alpha' > 0$.

The above step-size parameter updating occurs based on the sign changes of the error vector $e(\mu_n \to \mu_{n+1})\underline{\hat{a}}^*(\mu_n \to \mu_{n+1})$. If its sign changes consecutively for a specified number (m_0) of times, the step size is decreased. On the other hand, if its sign stays the same for another specified number (m_1) of times, the step size is increased.

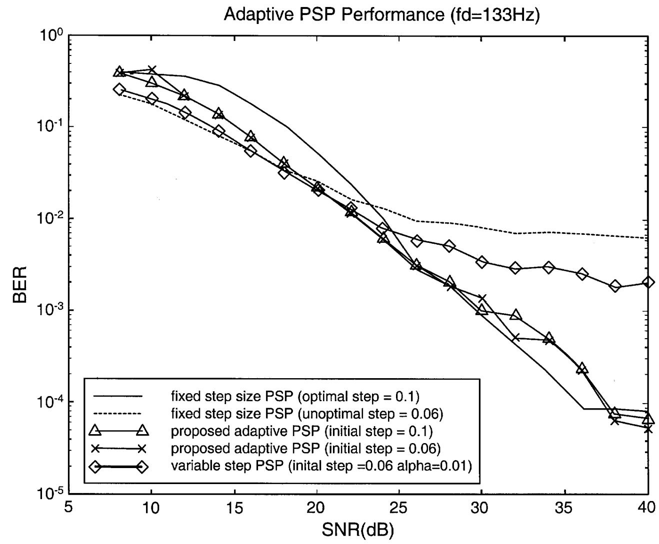

Fig. 1. BER of PSPs with $fd = 133$ Hz.

This VS algorithm proposed in [3] showed significant improvement over the conventional fixed step-size LMS with faster convergence and higher accuracy. Unfortunately, the above VS-LMS suffers from another drawback, i.e., the performance is very sensitive to the selection of another parameter α. The algorithm transfers the performance dependency on step size β into the dependency on step-size updating factor α. We propose a new step-size update scheme to eliminate the dependency on any selection of parameters. The new variable step-size algorithm is based on the absolute estimation error. The step-size updating scheme is given by

$$\begin{aligned}&\beta(\mu_n \to \mu_{n+1}) \\ &\quad = \min\left(\beta(\mu_{n-1} \to \mu_n) + |e(\mu_n \to \mu_{n+1})|, \beta_{\max}\right) \\ &\beta(\mu_n \to \mu_{n+1}) \\ &\quad = \max\left(\beta(\mu_{n-1} \to \mu_n) - |e(\mu_n \to \mu_{n+1})|, \beta_{\min}\right)\end{aligned} \quad (10)$$

where $e(\mu_n \to \mu_{n+1})$ is the estimation error on the last survivor path. The $\beta_{\max}$ and $\beta_{\min}$ are chosen to constrain the step size so that the mean square errors remain bounded while minimal tracking ability is obtained. The proof of the convergence of this algorithm is beyond the scope of this letter. All the results obtained here can also be applied to fractionally spaced receivers.

III. Results

The algorithms were tested with the IS-136 TDMA data packets with different Doppler shift frequencies. Figs. 1 and 2 show the algorithms' performance with Doppler frequency of 133 and 207 Hz, respectively. The solid curve represents the PSP with optimized step size. The dashed curve represents the PSP with unoptimized step size, which shows a significant degradation compared to the optimized case. The curve with diamond marks represents the PSP with variable step size but with fixed and unoptimized alpha. Although it has some

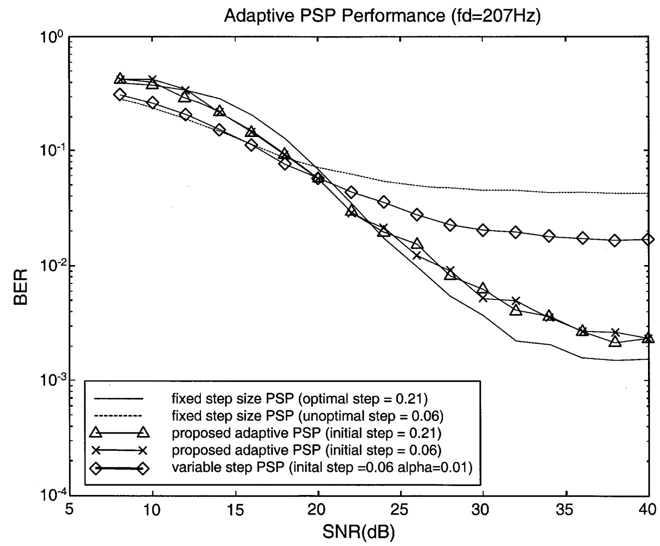

Fig. 2. BER of PSPs with $fd = 207$ Hz.

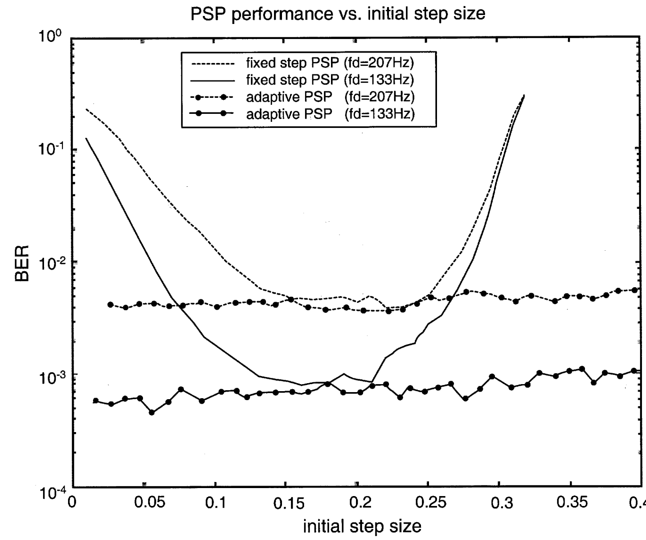

Fig. 3. PSP performance versus initial step size.

improvement over the PSP with fixed unoptimized step size, it still shows a large degradation compared with the optimized case. The two curves with triangle mark and cross mark, respectively, correspond to the proposed adaptive PSP with different unoptimized initial step sizes. It can approach the performance of the optimized PSP without knowing the optimized step size, and is independent of any selection of parameters. The optimal step sizes for the optimized PSP are obtained by trying the step sizes from 0.01 to 4.0 in steps of 0.01 and selecting the ones with the best performance (0.1 and 2.1 for $fd = 133$ Hz and $fd = 207$ Hz, respectively).

In Fig. 3, dashed curves and solid curves represent the PSP performance versus the selection of the initial step size when Doppler frequencies are 133 and 207 Hz, respectively. The two unmarked curves are the PSP with fixed step size, and the two dot-marked curves are the results with proposed PSP. It is shown that while the performance of the fixed step-size PSP highly depend on the selection of the step size, the proposed PSP is insensitive to the initial selection of the step size.

IV. Conclusions

The use of the proposed adaptive PSP [5] is particularly useful for mobile phones and other transceivers located in cars that are moving relatively fast with changing speed. In this environment, the variations of the channel are so fast that by utilizing a variable step-size factor, the system becomes more adaptive and the channel estimation will provide a more accurate estimation of the data. Further, the use of a variable step size allows each path to be independent of every other path. Notice that this technique is not limited only to the LMS algorithms/receivers. In general, techniques that utilize the estimated data sequence for channel estimation utilizing the LMS or RLS algorithms adaptively can use this approach in a PSP-based receiver. A similar approach may also be used with suboptimal algorithms such as reduced state-sequence estimation (RSSE) and delay decision frequency-sequence estimation (DDFSE).

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